Biomimetic design concepts for NASA zero-gravity exercise devices

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NIEA Nature Inspired Exploration for Aerospace
October 2017, OAI

Biomimicry Design and Application

3h course 3100:695 Thu 1:45-4:30 / TBD
open to Art, Biology, Engineering

Special Topics in Biology Spring 2017
Petra Gruber

Biomimetic Design Challenge
Spaceflight Exercise Equipment

The Design Challenge seeks bio inspired approaches for compact and efficient spaceflight crew exercise equipment accessories and interfaces to the crew. These concepts would seek to address challenges with implementing exercise in zero-gravity to include novel stowage and deployment features, improve crew comfort, and improve the efficiency of spaceflight exercise equipment (reducing mass and volume requirements on the vehicle).
Interdisciplinary design teams will cooperate with **NASA mentors** and other departments at the University of Akron taking on a specific **biomimicry and design perspective** to develop novel solutions and prototypes for the given design challenge.

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- Interdisciplinary Design Course Spring 2017
- University of Akron, Department of Biology
- Collaboration with and support from Human Research Program, NASA Glenn Research Center (GRC), Dr. **Gail Perusek**

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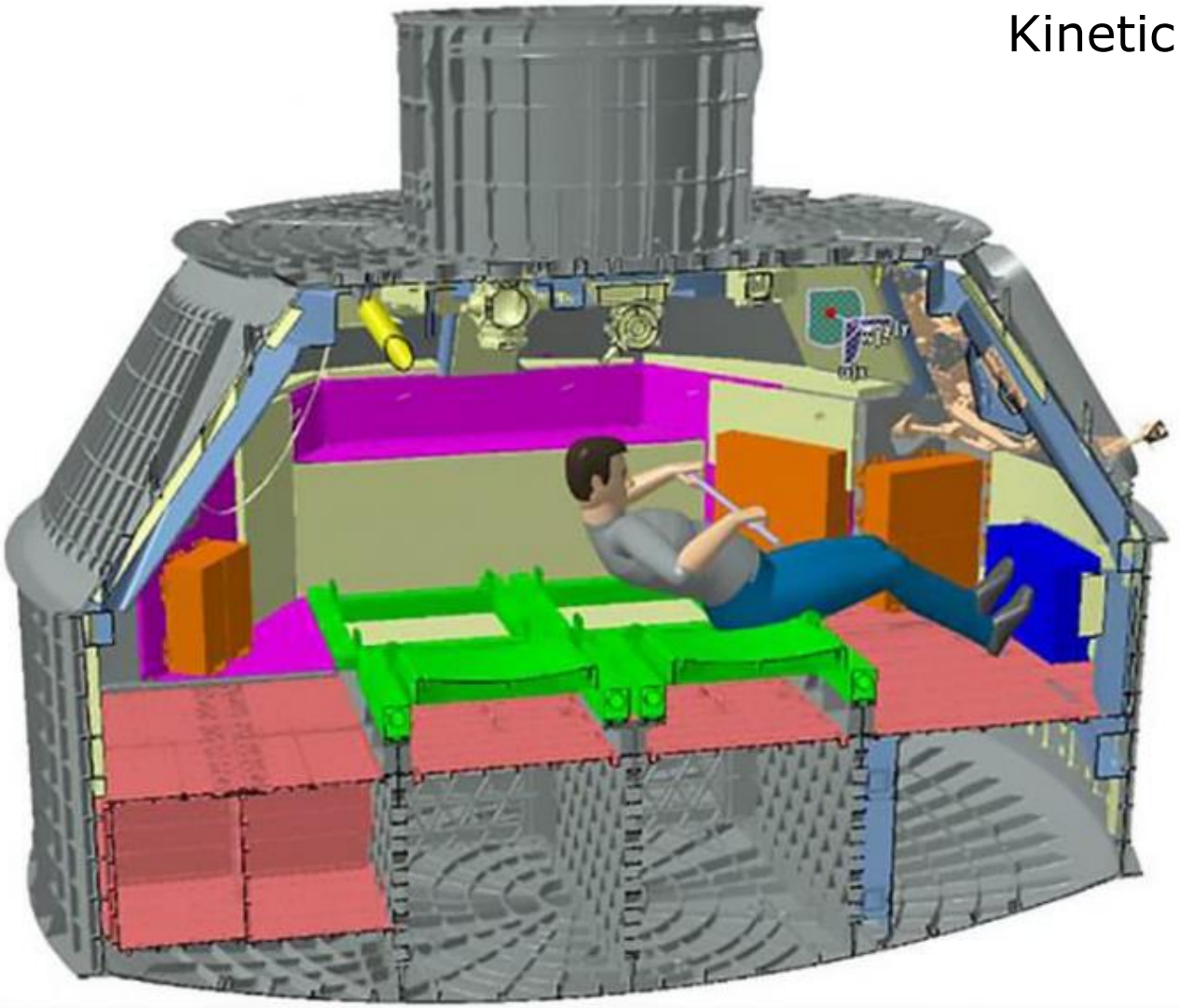
ORION and ROCKY



Cutaway of the Orion crew module, showing the ROCKY exercise device in blue, below the side hatch that astronauts will use to get in and out of the spacecraft. Credit: NASA

Resistive Overload Combined with Kinetic Yo-yo (ROCKY) prototype

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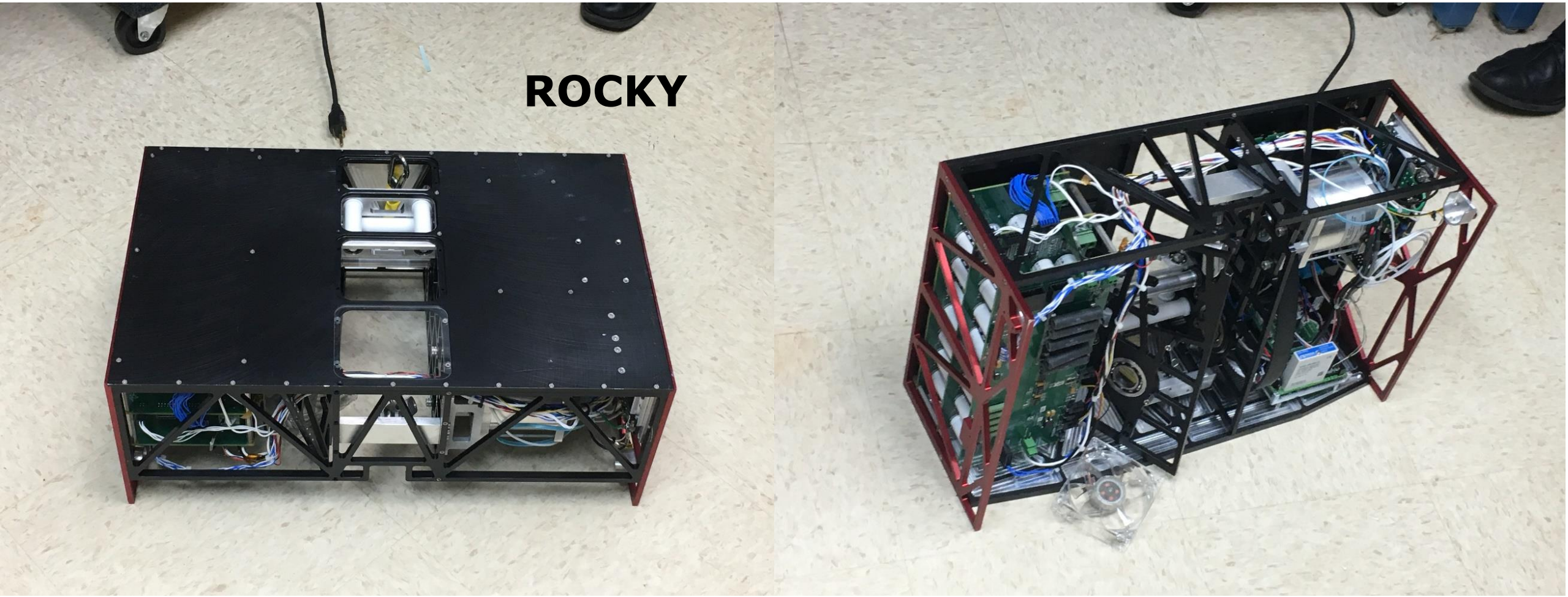
task and client



- box dimensions: 21''x13.5''x7.5''
- anthropometric variations require biomechanical adaptations
- wider stance can reduce risk of musculoskeletal injuries
- allows greater range of motion while performing exercises

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NAME	PROGRAM	EXPERTISE
Sebastian Engelhardt	IB Biomimicry	Biology, Energy Systems,
Ruwani Kiringoda	Arts&Sciences	Biology major, CIA Design
Sarah McInerney	IB Biomimicry	Zoology, Education
Sara Oliveira Pedro Dos Santos	Engineering	Engineer, Marine Biology
Amanda Pinheiro	Exercise Physiology	Physiology
Sayed Cyrus Rezvanifar	Biomedical Engineering	Biomed, Biomechanics
Kelly Siman	IB Biomimicry	Aviation, Politics
Elena Stachew	IB Biomimicry	Polymer Science, Engineering

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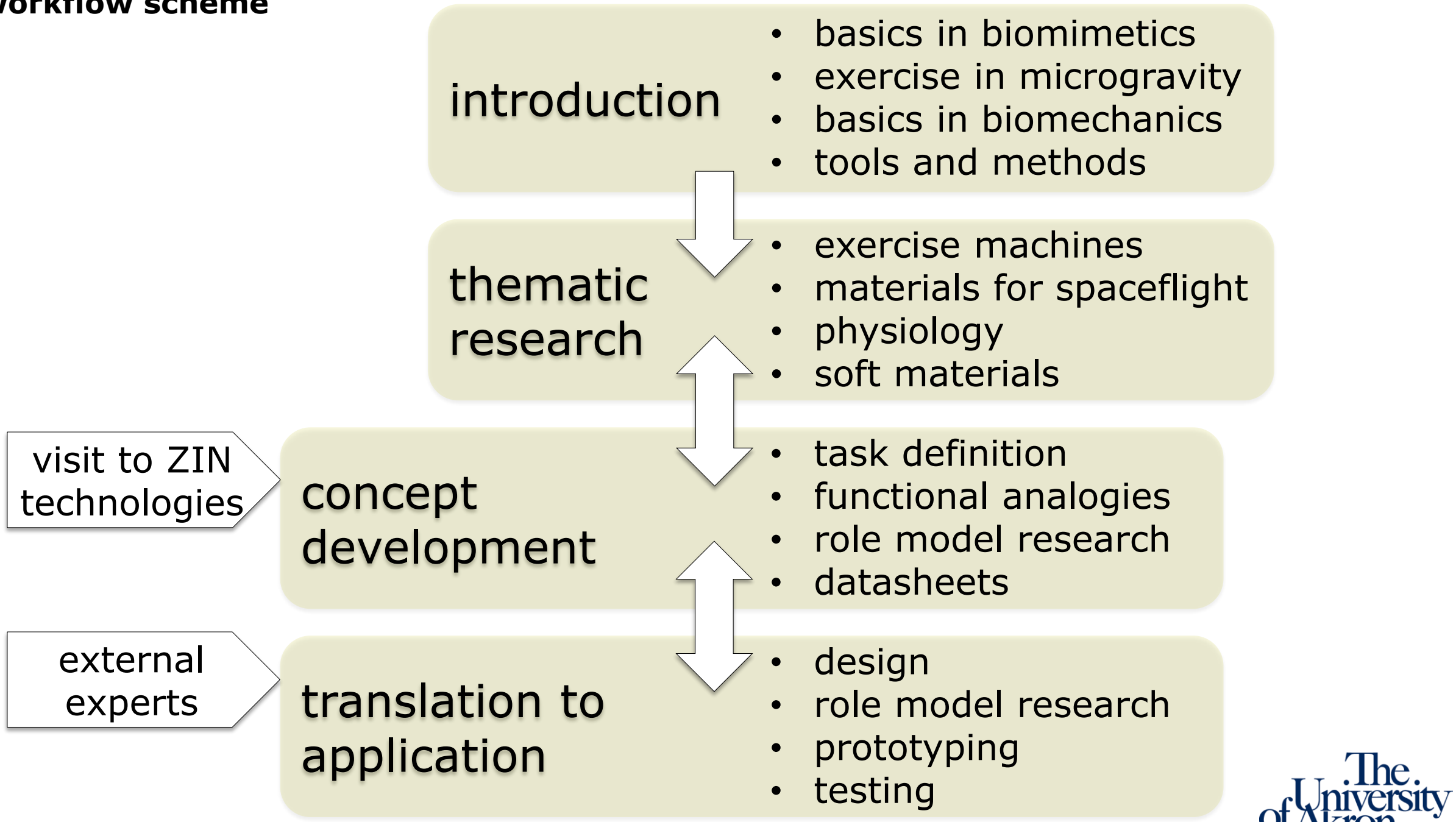
workflow scheme



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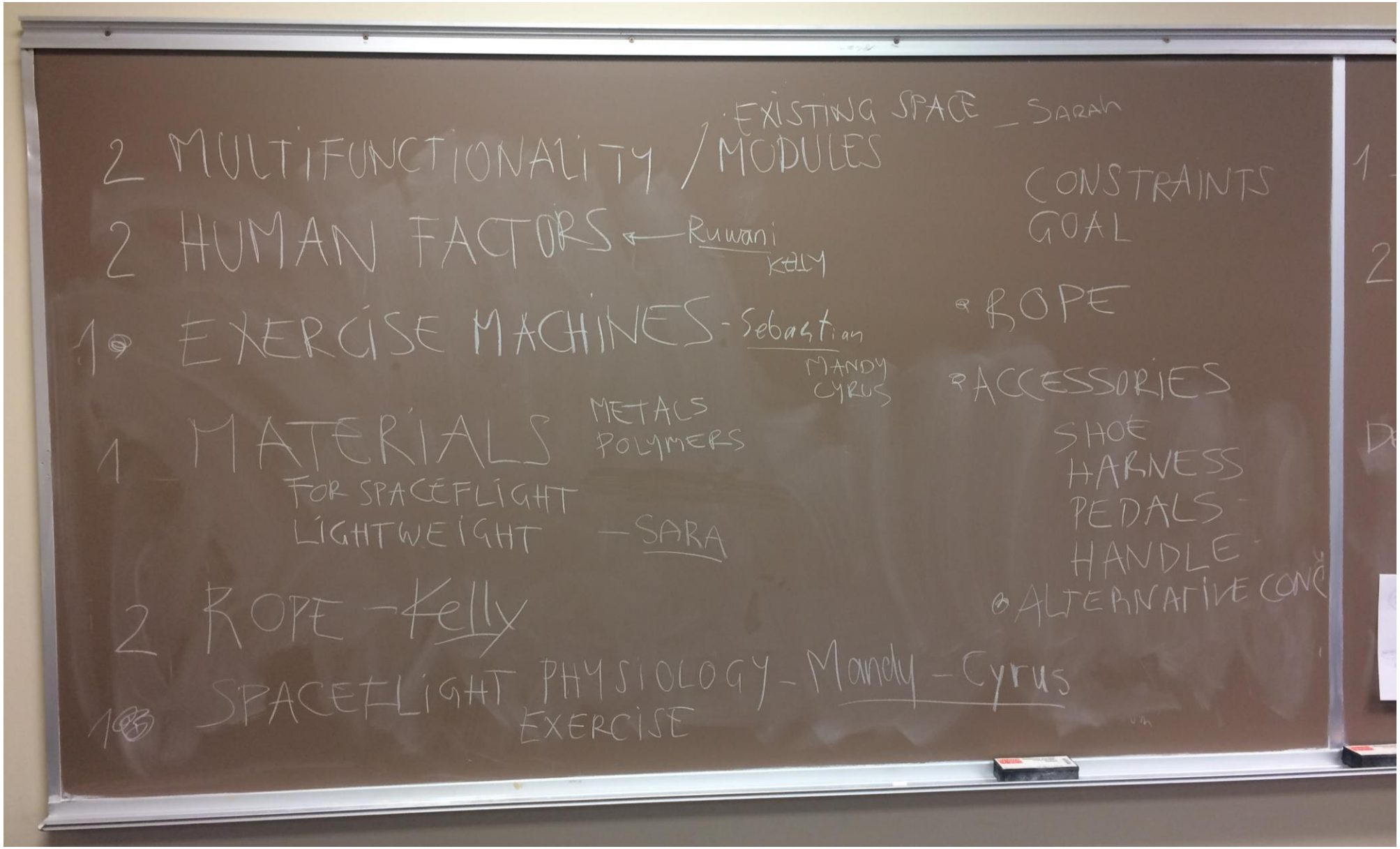
thematic research



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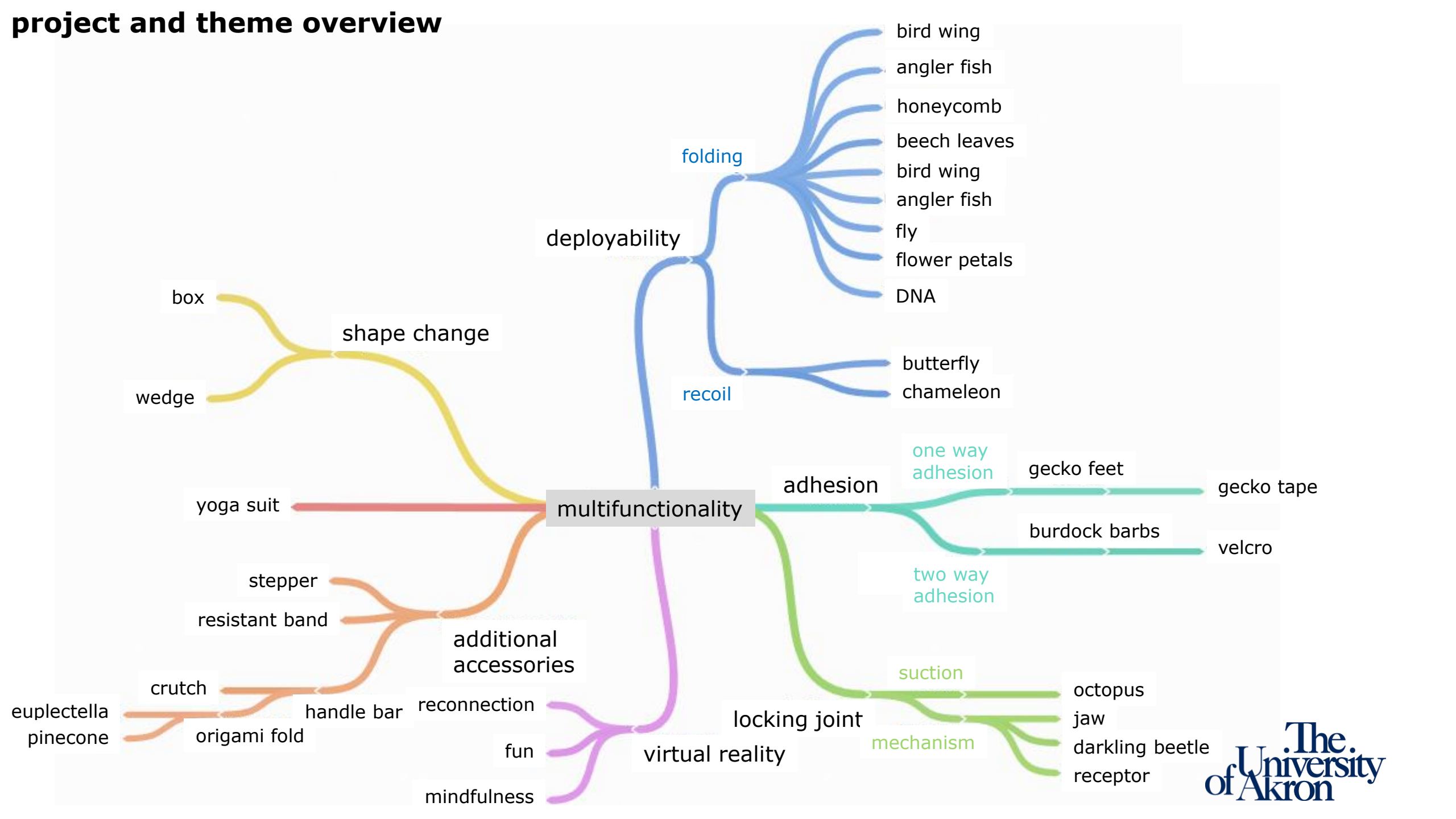
project and theme overview



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box accessories

- surface adhesion
- extended surface
- addition of accessories
  - handles
  - exercise band
- program

rope

- hierarchical structuring
- segmentation
- abrasion resistance – coating
- abrasion resistance – electricity and humidity

role models from biology

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accessories

explored key functions with biological model(s) for initial exploration:

- surface adhesion
  gecko, velcro

- extended surface
  folding structures, leaves and flower petals, bird feathers, honeycomb, angler fish, insect wings

- addition of accessories
  - handles
  - exercise band

  human physiology

- program and virtual reality
  psychology

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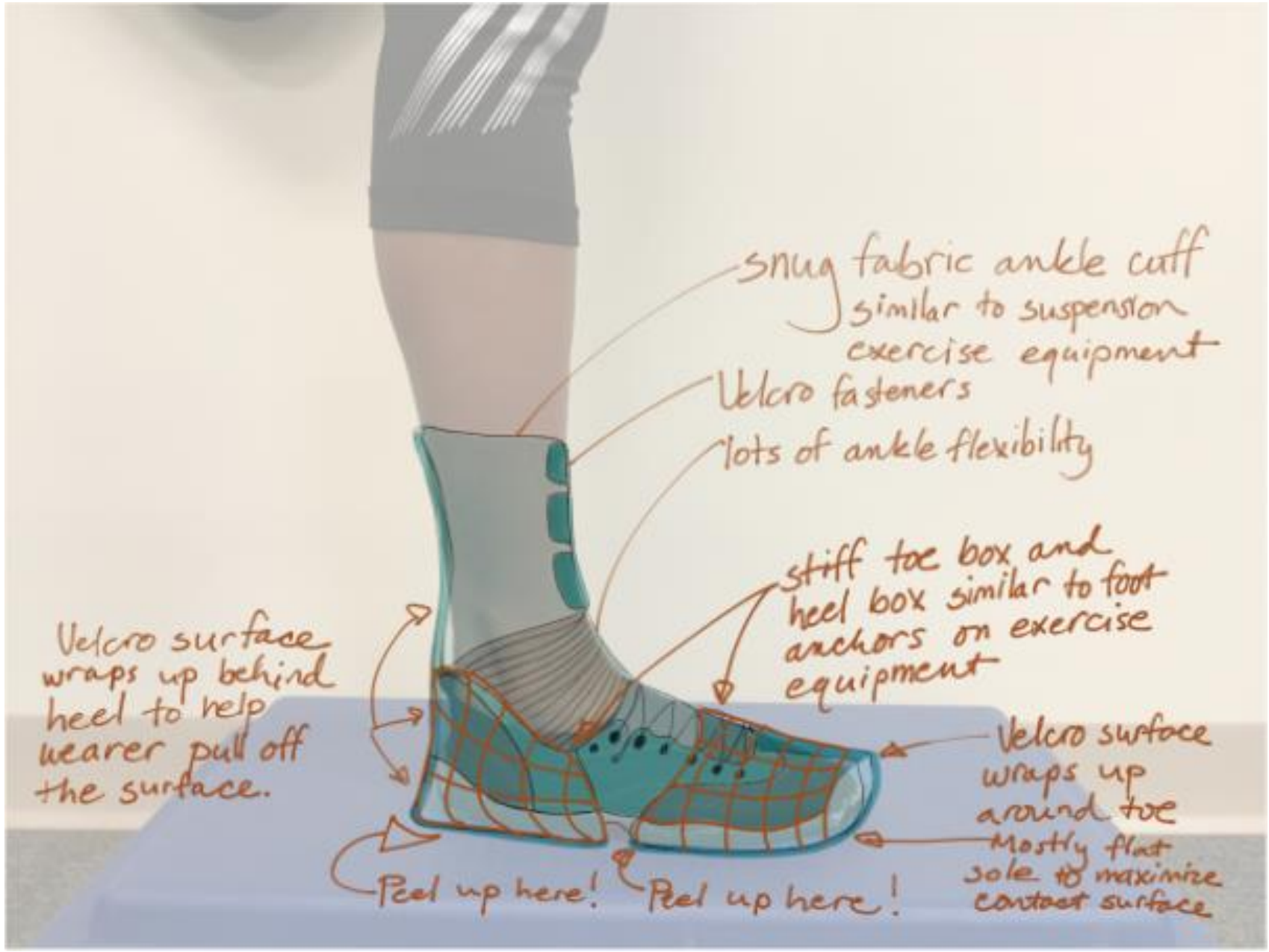
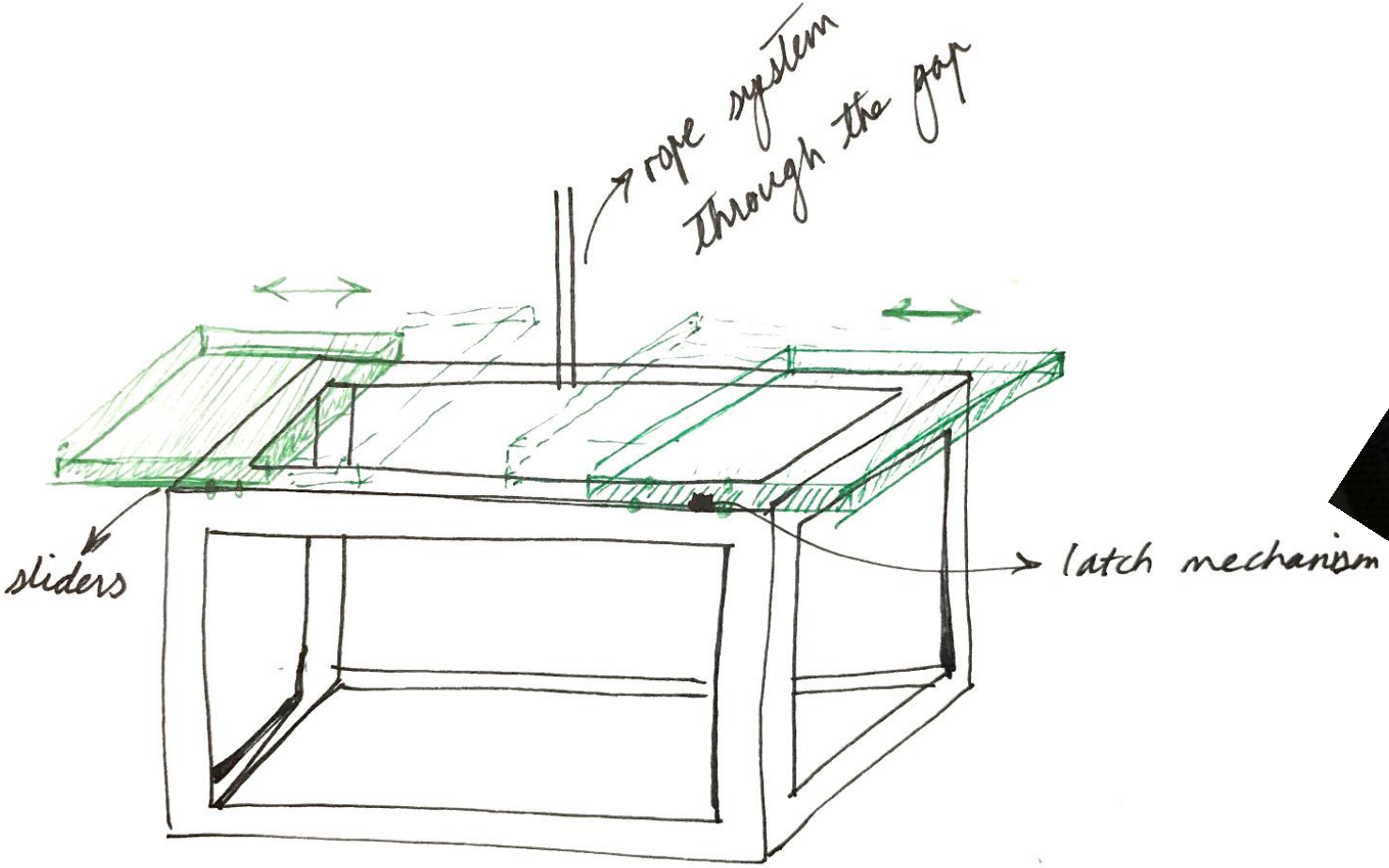
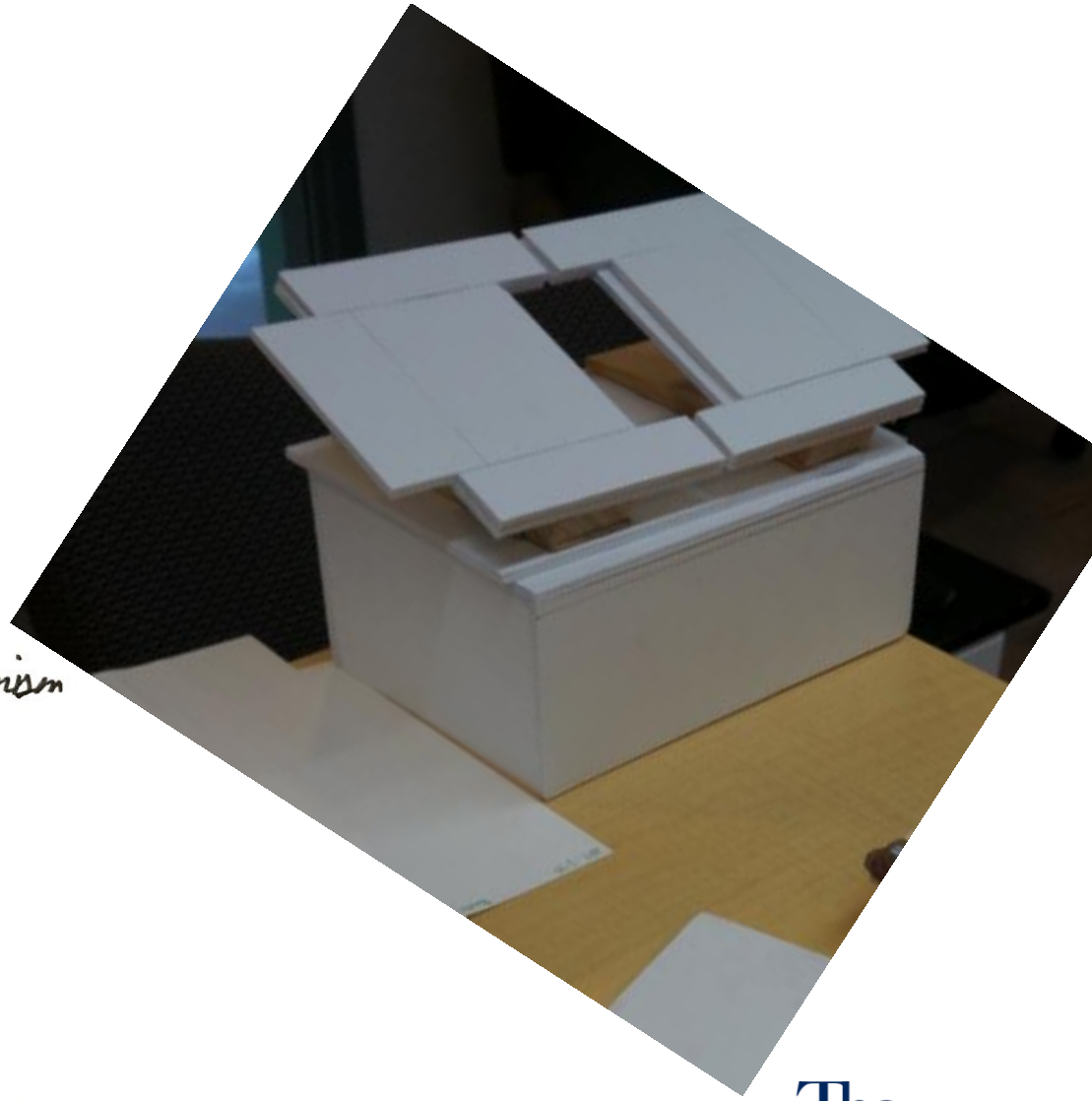
adhesion


Self-Anchoring Shoe
For Zero-G Exercise Platform


snug fabric ankle cuff similar to suspension exercise equipment
Velcro fasteners
lots of ankle flexibility
stiff toe box and heel box similar to foot anchors on exercise equipment
Velcro surface wraps up behind heel to help wearer pull off the surface.
Velcro surface wraps up around toe
Mostly flat sole to maximize contact surface
Peel up here!
Peel up here!

ACCESSORIES





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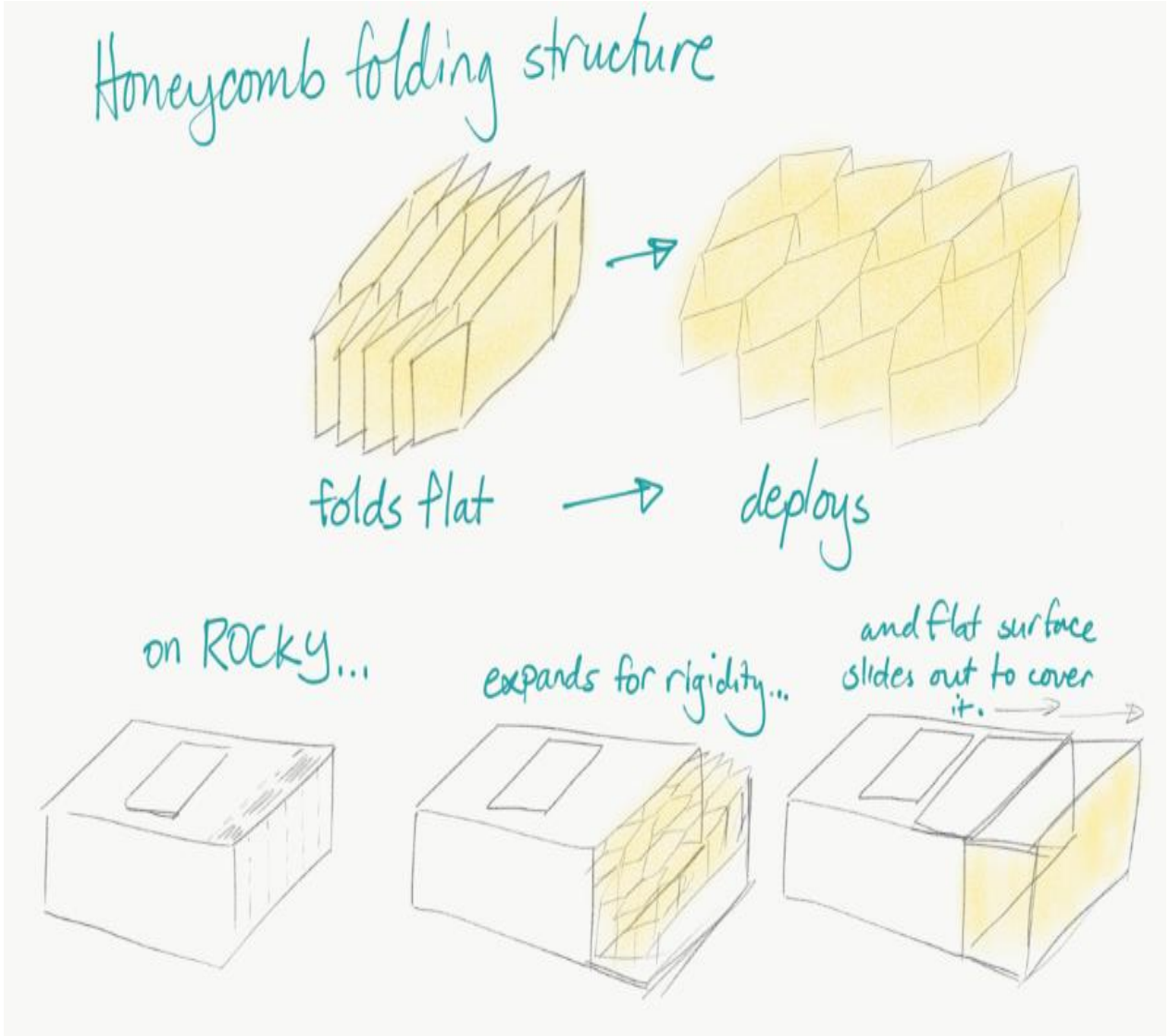
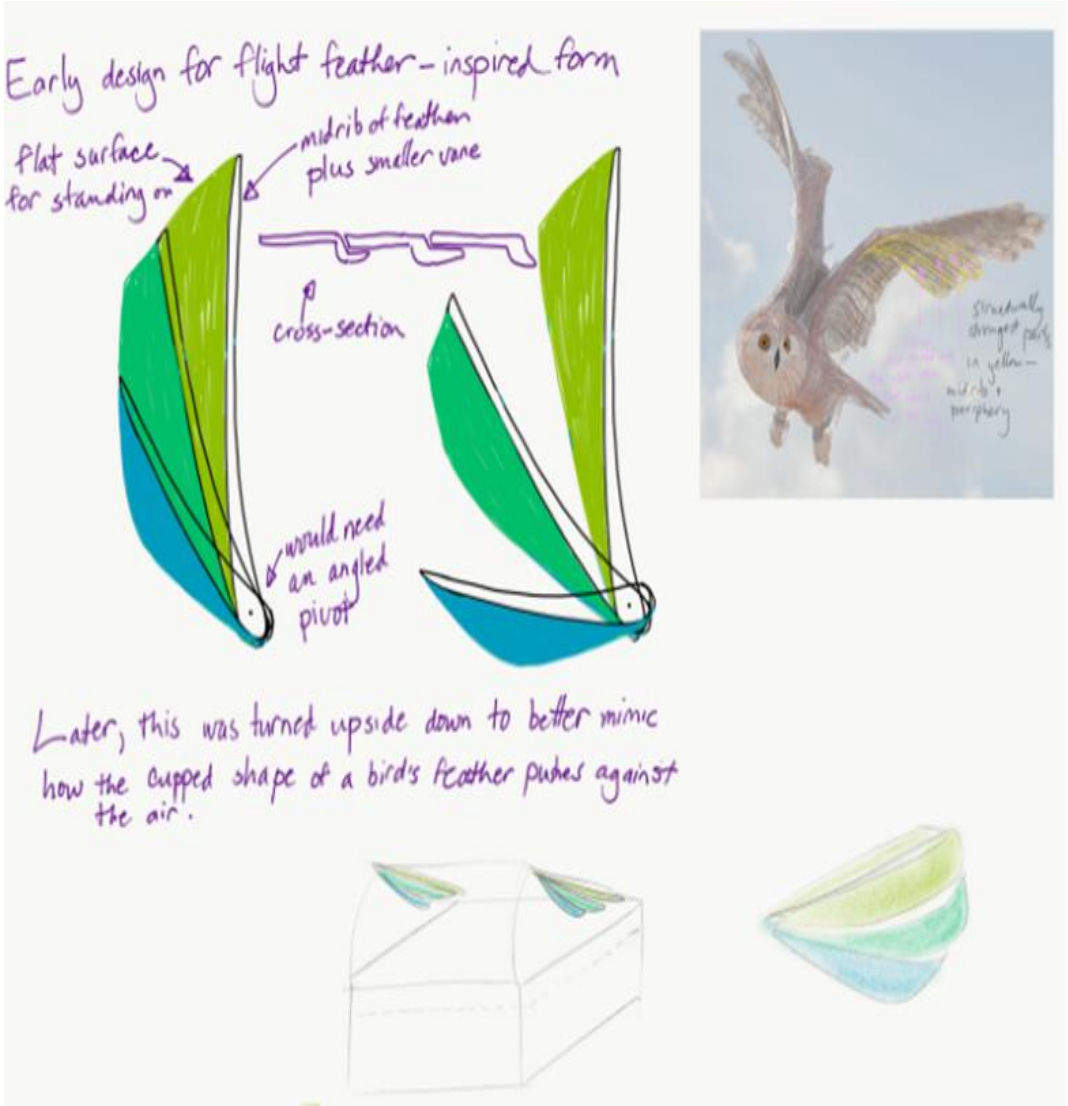
ACCESSORIES





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ACCESSORIES

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adjustments to handholds

- versatility of grips and hand holds
- diversify exercise equipment
- allow for different exercises to be done

exercise program

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exercise program

exercise program

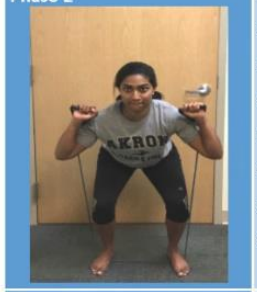
Curl to Squat to Press

Observer's Names:

Date: 5/4/17

Performer: Mandy Pinheiro

Equipment Required: Exercise band with handles

Illustration	Critical Elements	Yes	No	Major Muscles Used
Phase 1 	1. Feet **hip width apart standing on exercise band** 2. Toes point forward and slightly outward 3. Head **facing forward** 4. Core engaged 5. Elbows in extension alongside body 6. Forearms supinated & hands grasping handles 7. **Hands curl superiorly** with elbows tight to the body			• Biceps brachii • Brachialis • Deltoids • Rectus abdominis
Phase 2 	1. Supinate hands away from body 2. Head in line with **neutral spine** 3. Eyes looking up **4. Back straight and core engaged** 5. Hip cut backwards 6. Knee **flexion to 90°** 7. Knee stay behind toes 8. Return to standing position			• Rectus femoris • Vastus lateralis • Vastus medialis • Gluteus maximus • Rectus abdominis • Erector spinae
Phase 3 	**1. Shoulder blades squeezed together** 2. Chest 3. Core engaged 4. Head facing forward 5. Hands **press over head** 6. Arms locked out over head 7. Arms return to starting position			• Trapezius • Latissimus dorsi • Biceps brachii • Deltoid • Teres major • Teres minor

Wood Chopper

Observer's Names:

Date: 5/4/17

Performer: Mandy Pinheiro

Equipment Required: ROCKY device with handle attachment

Illustration	Critical Elements	Yes	No	Major Muscles Used
Preparation Phase 	1. Feet **hip width apart** 2. Toes point forward 3. Knees flexed 4. Head **facing forward** **5. Core engaged** 6. One hand grasps handle anteriorly 7. Other hand grasps handle anteriorly 8. Arm extended and locked out			• Flexor carpi ulnaris, • Flexor digitorum profundus • Palmaris brevis • Flexor digiti minimi • Opponens digiti minimi • Adductor pollicis • Flexor pollicis brevis
Execution Phase 	1. Legs stay put 2. Back straight and core engaged 3. Hands **pull handle diagonally** across body 4. Trunk is stabilized with a tight core **5. Arms stay locked out**			• Rectus abdominis • External oblique • Internal oblique • Transverse abdominis
Follow Through Phase 	1. **Finish the motion above the head** 2. Shoulders avoid excessive rounding 3. Trunk is still **facing forward** 4. Arms slowly lower to starting position			• Rectus abdominis • External oblique • Internal oblique • Transverse abdominis

rope

ARED on ISS
Provides bar and cable (rope) exercises and contains an inertial flywheel system to simulate the feel of 1-g free-weights
Deployed in January 2009 and continues to be in service today

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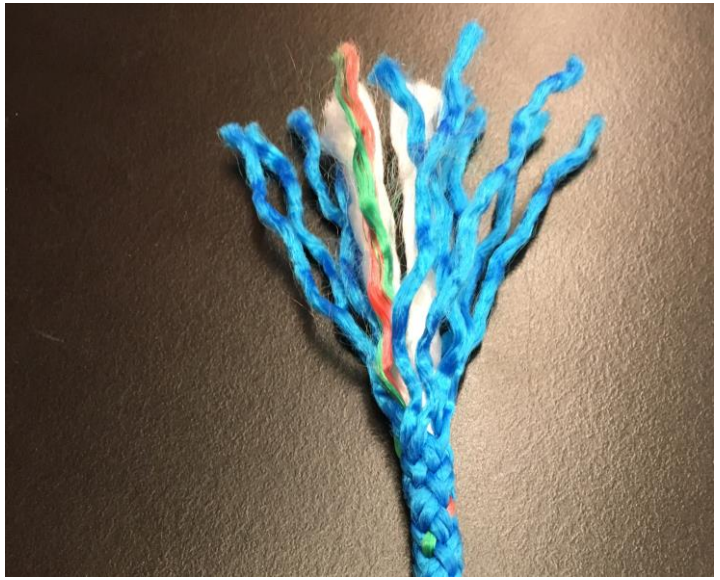
rope failure modes

Vectran Rope Wedged in Pulley


Polyester Rope Installed


Polyester Rope Splice Pull-Out


Polyester Rope With Lock Stitch



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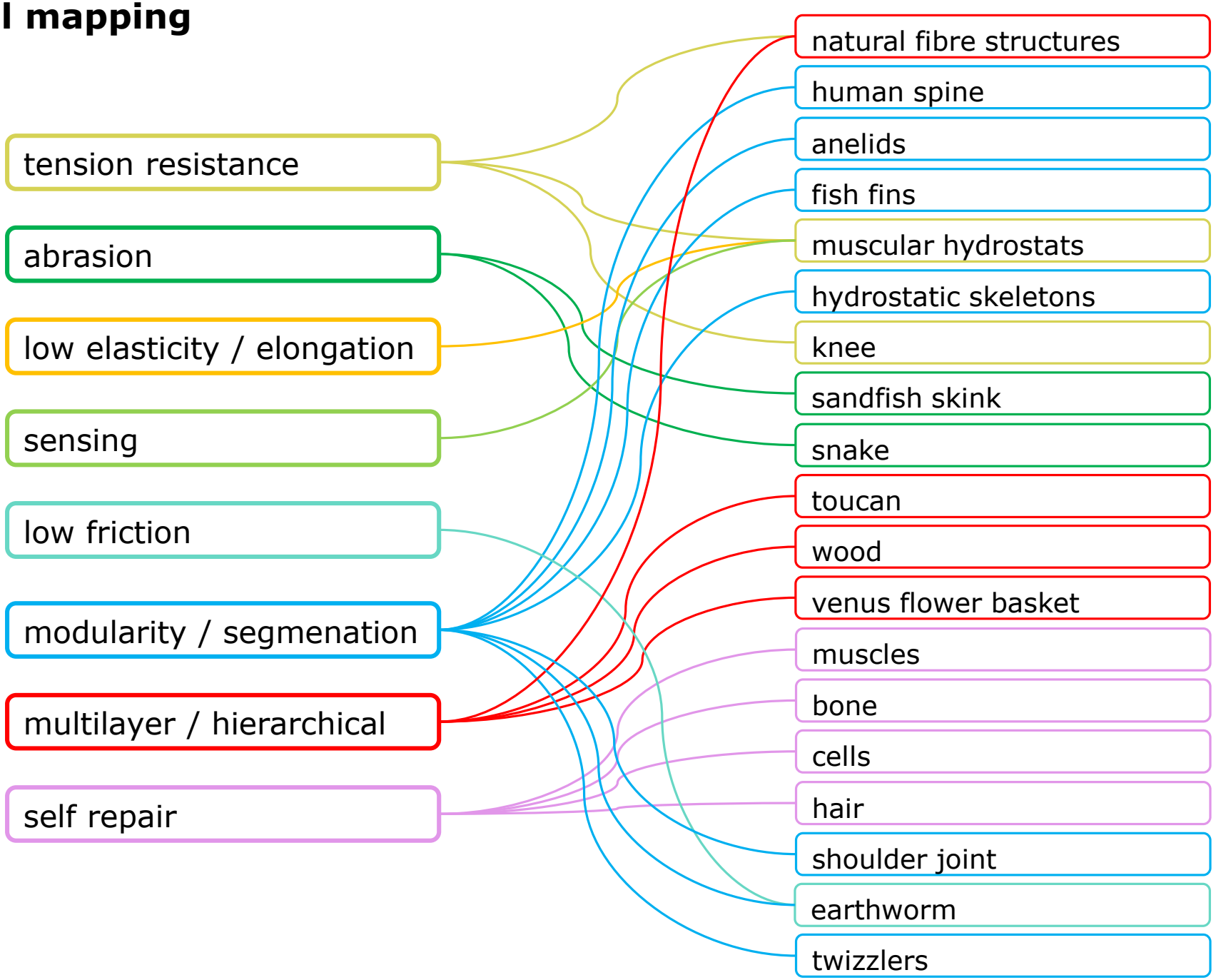
functional mapping



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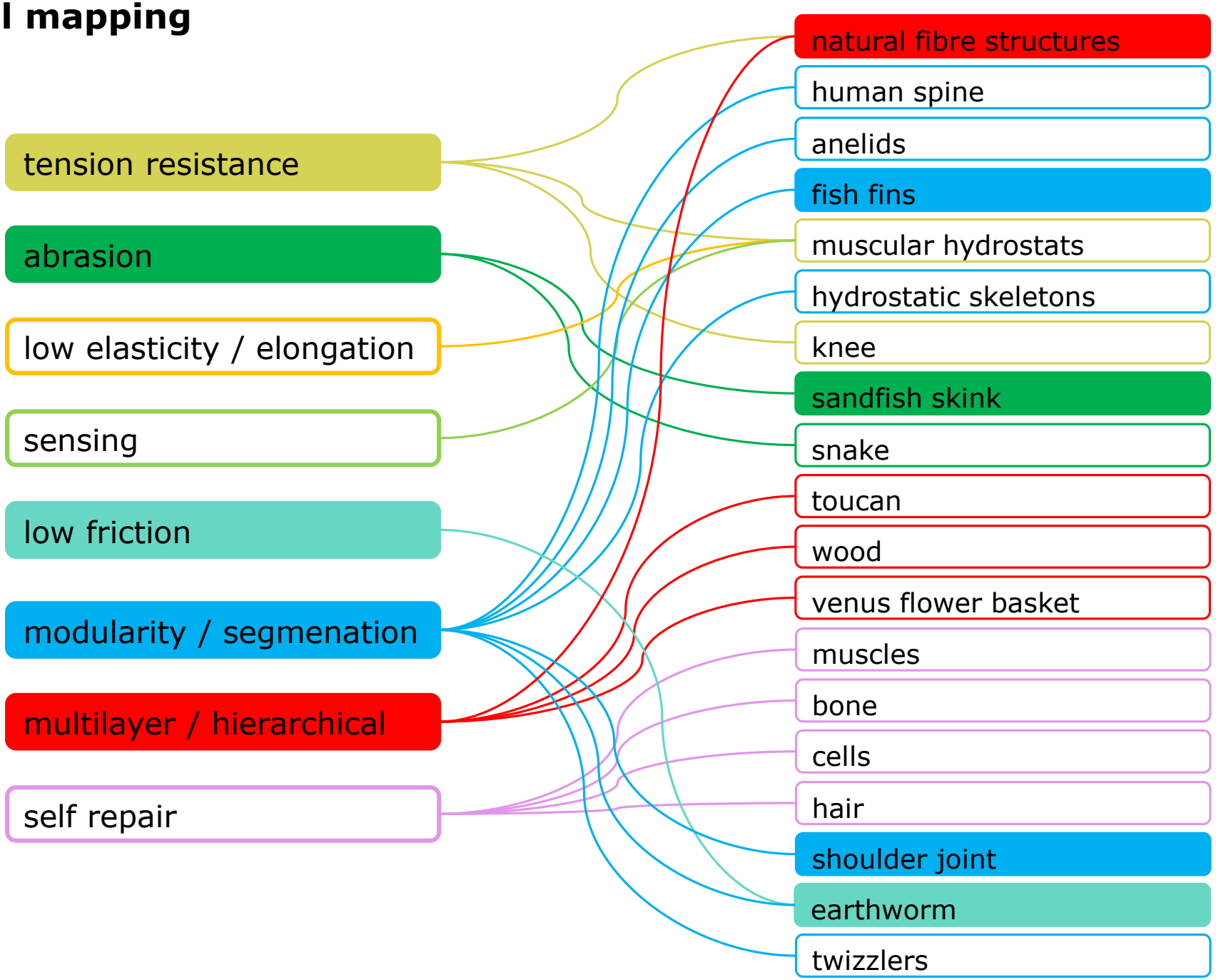
functional mapping



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explored 4 key functions with biological model(s) for initial exploration

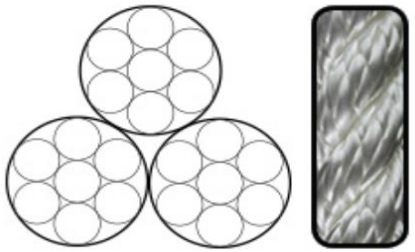
- hierarchical and structural as it relates to core strengthening
  natural fiber structures & wood fiber cell structure

- extend life of rope through modular replacement of most damaged area (segmentation)
  fish fins and shoulder joint

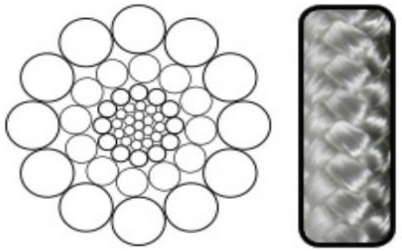
- abrasion resistance of rope
  sandfish skink for abrasion resistant coating or sheath

- abrasion resistance of the surface (i.e. pulley, flywheel)
  earthworm

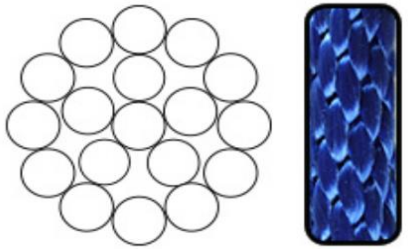
hierarchy



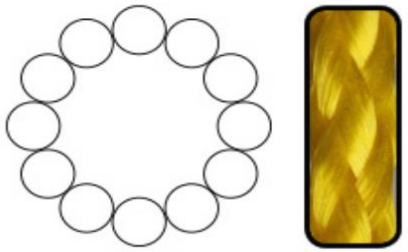
Twisted



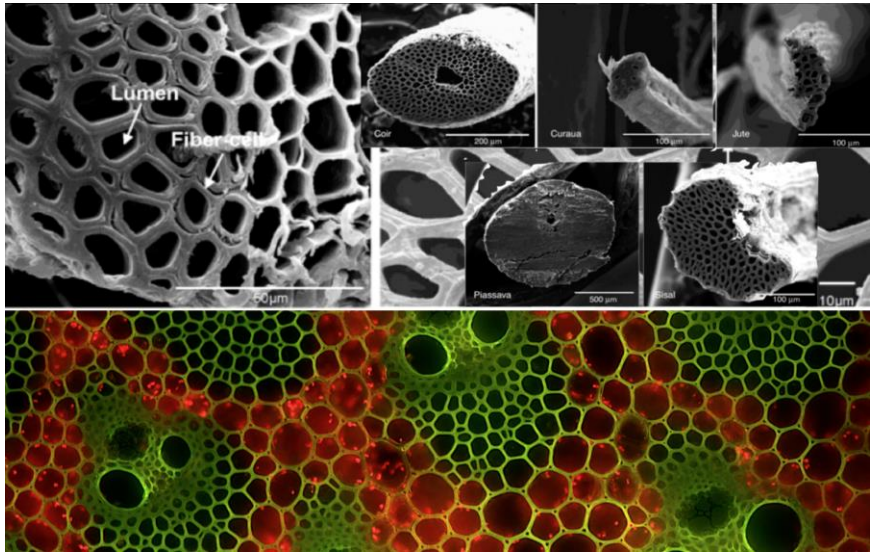
Double Braided

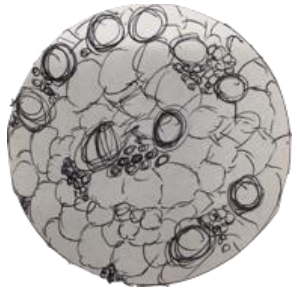


Solid Braided



Hollow Braided





Solid Braided Bamboo-Stem Inspired

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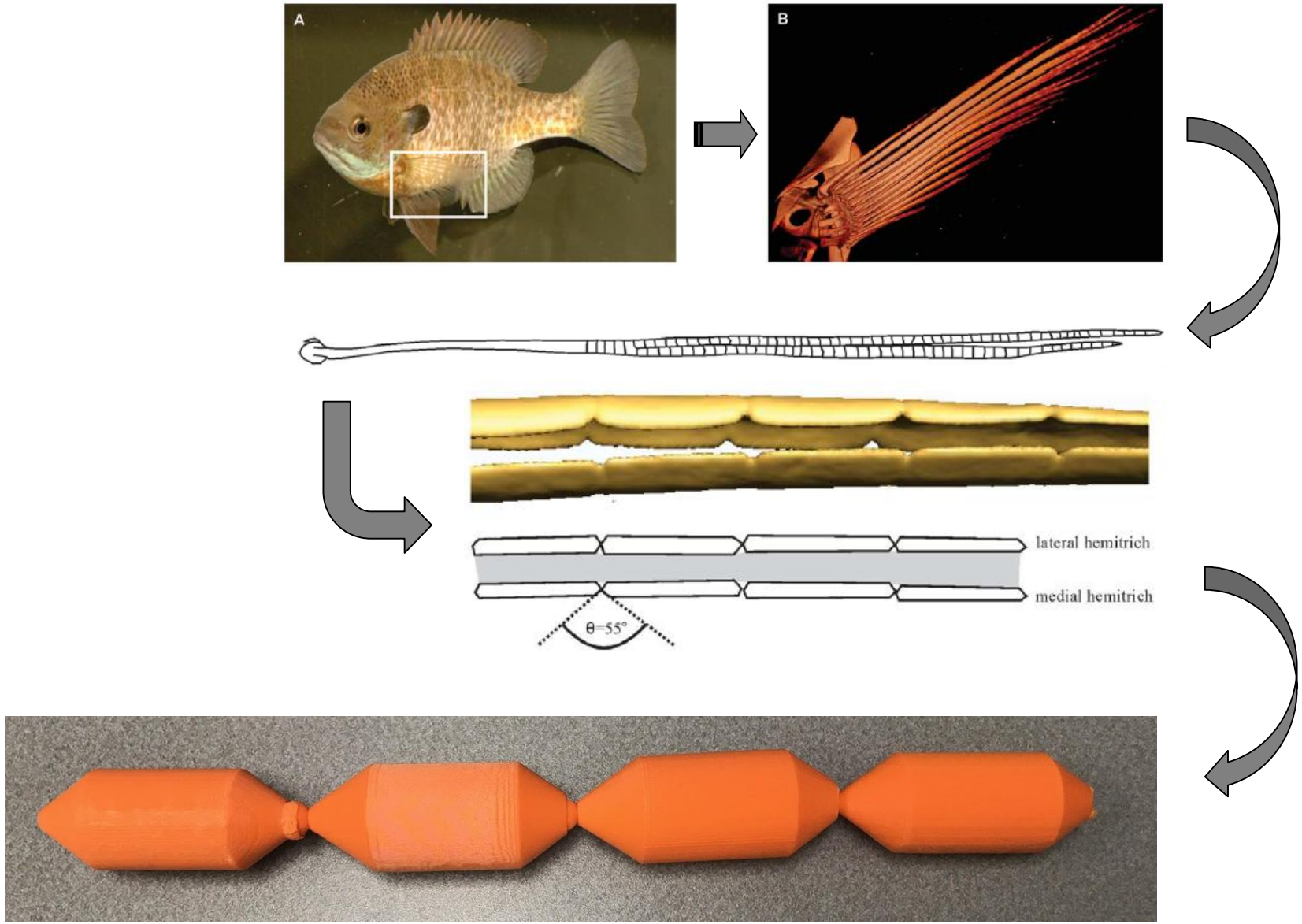
segmentation



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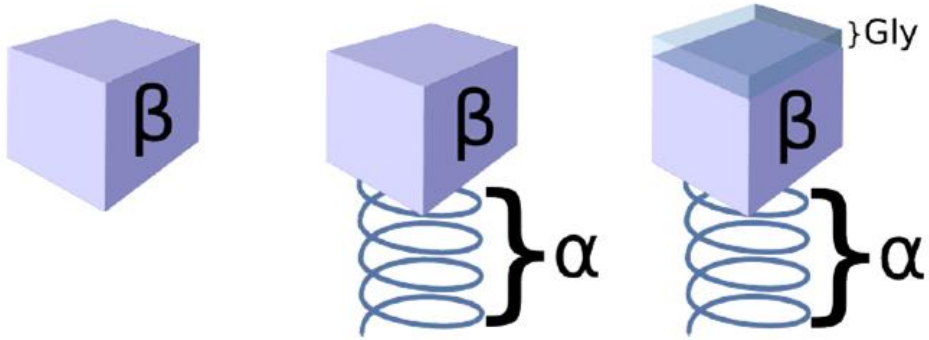
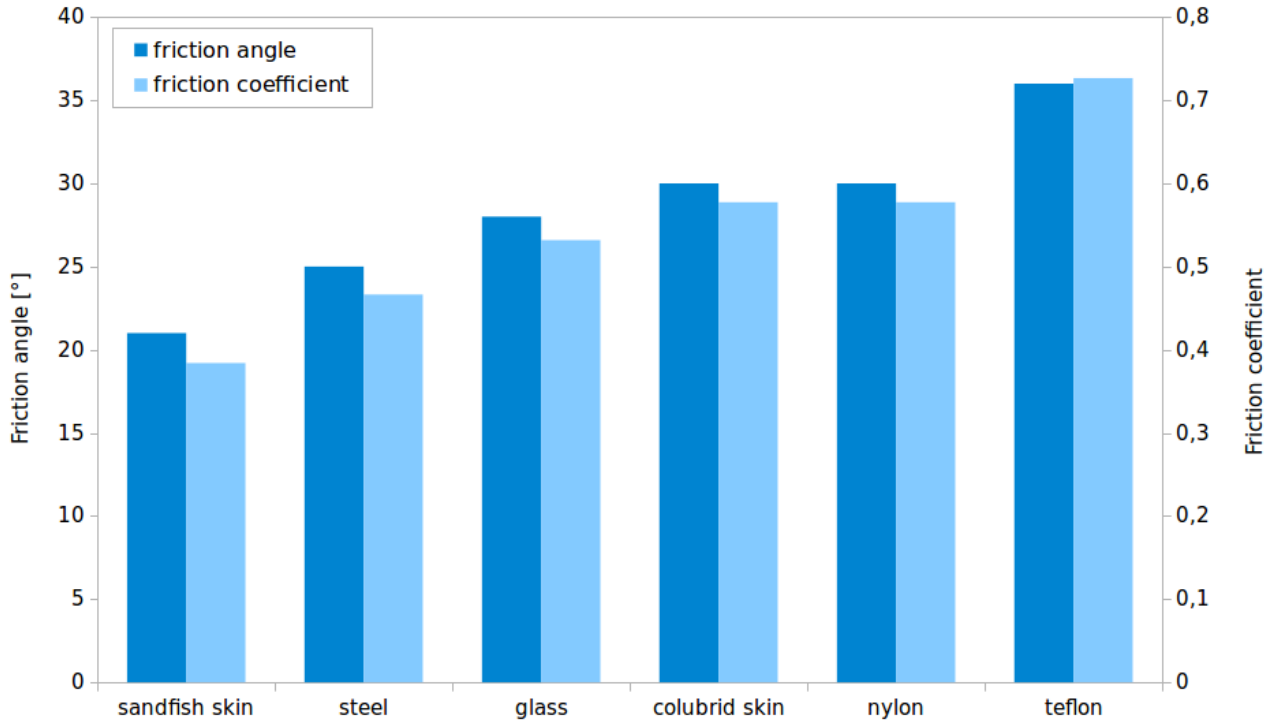
abrasion coating





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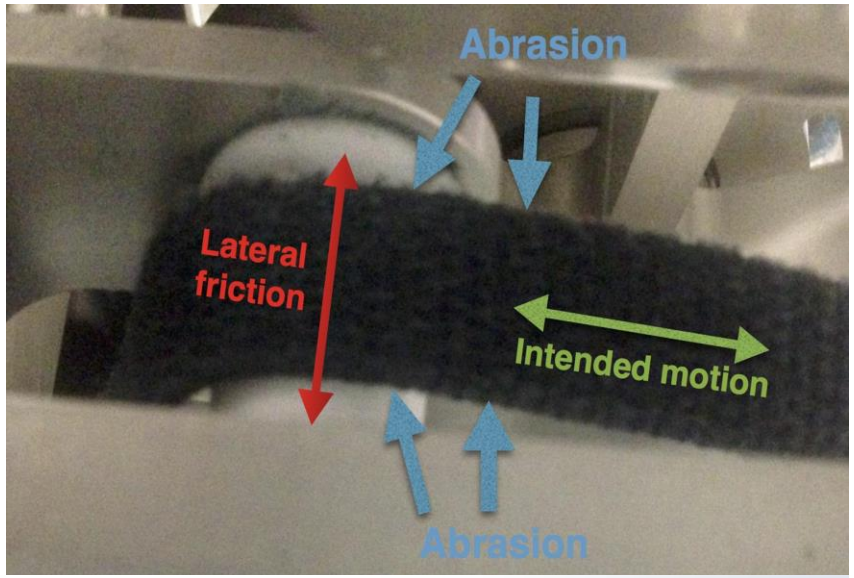
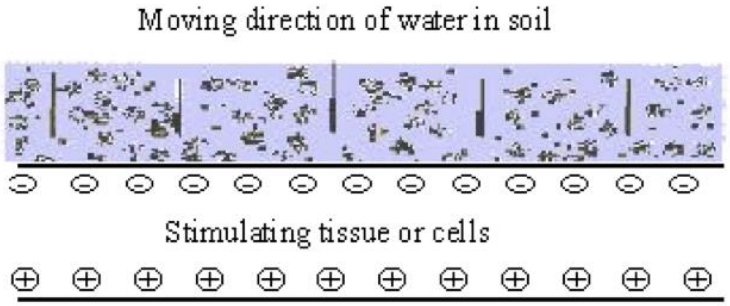
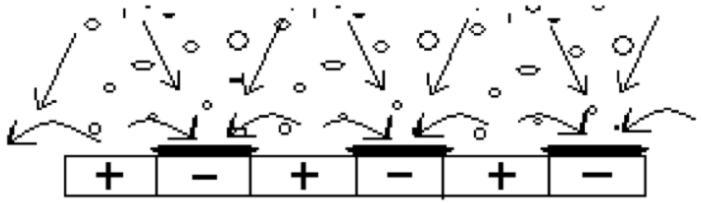
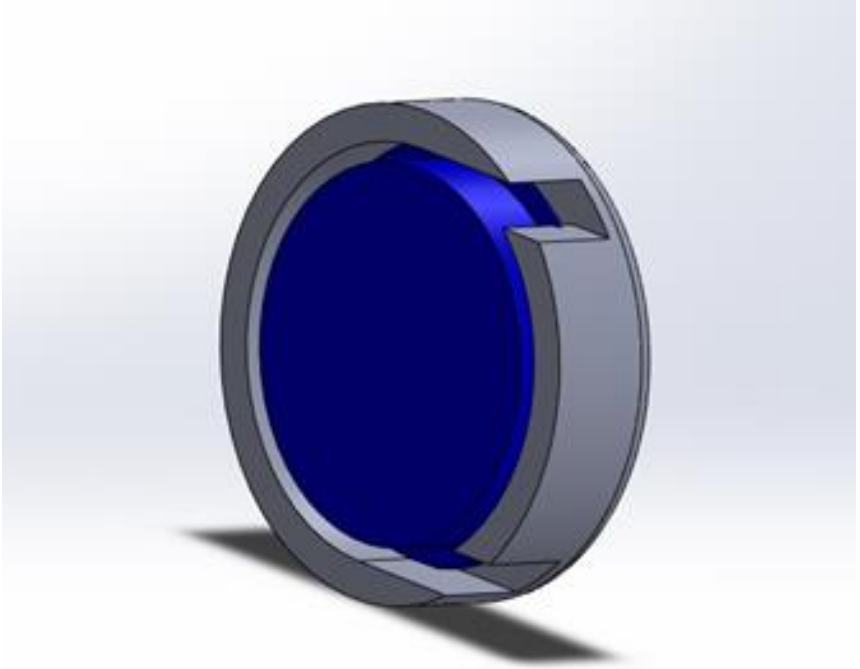
abrasion prevention by lubrication









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conclusion

- many interesting concepts generated
- task definition took a long time
- not enough time to do role model research
- good teamwork in interdisciplinary groups
- environment at UA allowed to call in external advisors in different areas

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thank you!

Sebastian Engelhardt
Ruwani Kiringoda
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Sara Oliveira Pedro Dos Santos
Amanda Pinheiro
Sayed Cyrus Rezvanifar
Kelly Siman
Elena Stachew

Gail Perusek, Nasa Glenn
Henry Astley
ZIN Technologies, Justin Funk

ZIN Technologies

BIOMIMICRY RESEARCH INNOVATION CENTER

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